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CALCULATING IRRIGATION REQUIREMENTS

for eastern Vancouver Island

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Province of British Columbia
Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

APD Technical Paper 10

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C.H. Wallis
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Victoria, B.C.
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PREFACE

This paper has been prepared as a part of the Agricultural Land Reserve Fine Tuning Program, and was funded by the B.C. Ministry of Agriculture and Food. It is intended to aid in agricultural land use classification and planning by providing a readily useable method of estimating plant water requirements for sites with different soil and climatic characteristics.

Values of irrigation requirement, excluding losses due to inefficient application, are calculated for different soil types in the Duncan area, for shallow and deep-rooted crops, for average and droughty conditions. Inadequacies in the available data are discussed and suggestions are made to improve the estimates for operational use.

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A soil moisture advisory group provided assistance in preparing this paper. The group included R. Davis and M. Coligado (Air Studies Branch); N. Sprout, R. Louie, N. Nagpal, J. Jungen and P. Sanborn (Terrestrial Studies Branch); E. Schulz and M. Driehuyzen (Ministry of Agriculture and Food).

Dr. M.C. Coligado provided climatic data and interpretations. He also co-authored Appendix C on calculation of potential evapotranspiration, and provided Figures C1 and C2, which demonstrate the importance of the maritime influence on climate. Mr. Paul Sanborn compiled the soil data shown in Appendix A, and helped in their interpretation.

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GLOSSARY OF TERMS

1. EVAPOTRANSPIRATION (ET) - is the loss of water from a surface in vapour form, through evaporation and transpiration via plant stomata.

2. POTENTIAL EVAPOTRANSPIRATION (PE) - is the maximum (energy-limited) evapotranspiration rate from an extensive well-watered surface, fully covered with short, actively growing vegetation.

3. ACTUAL EVAPOTRANSPIRATION (E) - is the evapotranspiration loss from a surface, which may be limited by either water or energy supply. During non-limiting moisture conditions, E from a fully covered vegetated surface equals PE.

4. CONSUMPTIVE USE FACTOR (CU) - is the ratio of E to PE under non-limiting moisture conditions. If plant cover is incomplete, and the soil surface is dry, E may be less than PE even though the plants experience no water stress. When E equals PE, CU equals 1. In situations where excess energy from surrounding drier areas is available for evapotranspiration (advective conditions), the CU may exceed 1.

5. AVAILABLE WATER STORAGE CAPACITY (AWSC) - refers to the amount of water stored within the root zone which is available to plants. In this report AWSC is defined as the amount of water extracted between 0.033 and 1.5 MPa (1/3 and 15 bar) tensions.

6. READILY AVAILABLE WATER STORAGE CAPACITY (SC) - is water stored within the root zone which is available to plants without limiting E. In this report half of AWSC is considered to be readily available. (Availability coefficients for various crops are listed in the B.C. Irrigation Design Manual).

7. IRRIGATION REQUIREMENT (IR) - is the amount of water needed to maintain crop evapotranspiration at the potential rate when SC has been

exhausted. The irrigation requirement calculated from climatic data must be increased by the amount of any runoff or drainage, and decreased by the amount of any seepage or subirrigation within the root zone.

8. CLIMATIC MOISTURE DEFICIT (CMD) - is the difference between PE and precipitation (P). It does not indicate the actual deficit, since the temporal distribution of rainfall, and the soil AWSC affect the proportion of P retained as root zone storage, and that which is lost as runoff.

9. CLIMATIC MOISTURE INDEX (CMI) - is an index of the efficiency of growing season precipitation in meeting growing season crop water requirements. It is written as follows:

$$CMI = [P/(P + SC + IR)] \times 100$$

It is assumed that the soil is fully recharged with moisture at the beginning of the growing season.

10. RISK - refers to the probability of occurrence, in this case of a given irrigation requirement. 50% risk implies that one year in two the calculated irrigation requirement will be exceeded by the actual requirement, while at a 10% risk level the calculated IR will be exceeded one year in ten.

CHAPTER ONE
INTRODUCTION

Although the eastern coastal area of Vancouver Island has an annual rainfall surplus, crops are subjected to significant soil moisture deficits during the growing season. Since the magnitude of the winter water surplus is several times that of the summer deficit, it may be practical to use stored runoff for irrigation. The following excerpt from a 1953 Agriculture Canada report (Webster, et al., 1954) shows that the need for irrigation, and its potential benefits, have long been recognized.

"Irrigation is becoming an important farm practice on Vancouver Island. The southern portion of the Island, in particular, is very dry. The rainfall for May, June, July and August averages only 95 mm. During these months 450 mm of water is evaporated from a free water surface. These figures indicate the need for irrigation and conservation of soil moisture."

Experiments conducted at that time showed that irrigation results in significant crop yield increases compared to dryland conditions. In addition, irrigated crops are generally higher in quality, and therefore considerably more marketable (Webster, et al., 1954). Provided that water can be delivered economically and in sufficient quantities, the potential for improvement of existing agricultural land is significant. Although irrigation is widely used, little quantitative information exists on the magnitude or variability of irrigation requirements.

This technical paper has been designed to meet the following objectives:

1. To develop a simple method for calculating growing season water deficits from climatic and soil data.
2. To calculate water deficits for the soils near Duncan, on the east coast of Vancouver Island, considering several combinations of rooting depth, drought risk, and plant water use. Irrigation requirement has been mapped for a small pilot area at Dougan Lake.

3. To evaluate the Climatic Moisture Index (CMI), particularly in terms of its scale of resolution, comparing areas with differing soil and climatic characteristics.

CHAPTER TWO
BACKGROUND AND DEVELOPMENT OF THE CALCULATION PROCEDURE

2.1 WATER BALANCE IN THE SOIL-PLANT-ATMOSPHERE SYSTEM

The calculation of water requirements requires knowledge of water supply and demand. In general, precipitation is the major source of water supply, but contributions from lateral inflow (seepage) and capillary rise from the water table (sub-irrigation) can enhance the supply. Evapotranspiration (ET) provides the primary water demand, but water losses from the rootzone via lateral outflow and drainage must also be considered. The water balance equation is summarized in equation 1 below, and illustrated in Figure 1,

$$\Delta S = P - ET + (L_i - L_o) + (C - D) \qquad (1)$$

where ΔS is the change in root zone water storage, P is the precipitation, L_i and L_o are the surface and subsurface lateral inflow and outflow, respectively, and D and C are the drainage and capillary rise, to and from the water table, respectively.

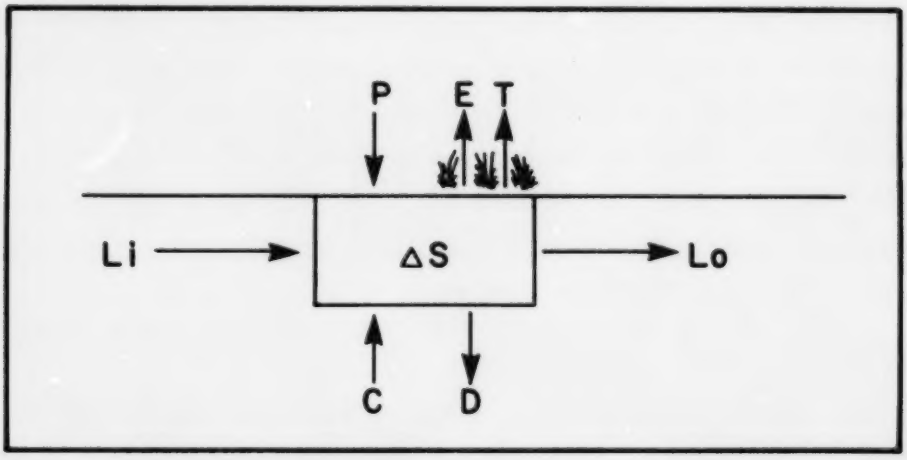


Figure 1 ROOT ZONE WATER BALANCE COMPONENTS.

2.2 CALCULATING THE CLIMATE MOISTURE DEFICIT

The simplest water deficit calculations assume negligible lateral and vertical flow, and consider only the rainfall and evapotranspiration terms of the water balance. The difference between these terms is called the Climatic Moisture Deficit (CMD) calculated as follows:

$$CMD = PE - P \qquad (2)$$

where PE is potential evapotranspiration. Table 1 shows values of P, PE and CMD for several B.C. locations calculated on a seasonal (May to September)

TABLE 1: RAINFALL, POTENTIAL EVAPOTRANSPIRATION, AND CLIMATIC MOISTURE DEFICIT FOR SEVERAL B.C. LOCATIONS

Location	May - Sept. Seasonal Total (mm)			Annual Total (mm)	
	Rain	PE	CMD	Rain	CMD*
Victoria (Gonzales)	108	318	210	657	- 294
Saanichton	140	342	202	838	- 460
Cowichan Bay	157	347	190	961	- 565
Duncan	158	461	303	1042	- 516
Port Alberni	249	439	190	1971	-1470
Comox	189	364	175	1206	- 791
Vancouver	302	335	33	1494	-1116
Abbotsford	152	500	348	480	79
Princeton	254	424	170	442	33
Kamloops	117	554	437	254	389
Creston	122	472	350	358	178
Fort St. John	224	371	147	1082	- 663

* Negative value indicates surplus.

and annual basis. From the values of CMD in Table 1 it can be seen that the seasonal deficits experienced on Vancouver Island are less than those for interior locations such as Creston and Kamloops, but they are significant nonetheless. It can also be seen that, unlike many interior locations, the winter surplus exceeds the growing season deficit.

The values of PE in Table 1 are calculated by the Baier and Robertson (1965) equation, adjusted to coastal conditions (see Appendix C). Comparison of the values calculated from the Baier and Robertson equation and from Priestley and Taylor (1972) showed differences of the order of 25% in areas exposed to a strong maritime climatic influence. If the Priestley and Taylor formula with an α-value near 1.25 is applicable to this maritime area with its distinctive atmospheric moisture characteristics, then the values in Table 1 could be a significant underestimate of the actual PE. (A field study proposed for the 1981 and 1982 growing seasons is aimed at resolving this problem, but the current estimates represent the best which can be made from existing data. Appendix C contains further discussion of these differences.)

CMD differs from irrigation requirement (IR) since it assumes that all of the rainfall infiltrates the soil and that none is lost as runoff. Also, the CMD calculation does not include the storage capacity of the soil, which provides water to the plant from rain stored at the start of the growing season. A large available water storage capacity (AWSC) acts as a buffer against short-term water deficits, and reduces the frequency and magnitude of IR, while permitting larger single applications of water without waste.

2.3 CALCULATING THE IRRIGATION REQUIREMENT

Several techniques are available for estimating irrigation requirements from climatic data (Robertson and Holmes, 1959; Ayres, 1965; Baier and Robertson, 1967; Baier, Robertson and Clarke, 1969). Irrigation requirements have been calculated from a daily water budget based on 30 years of

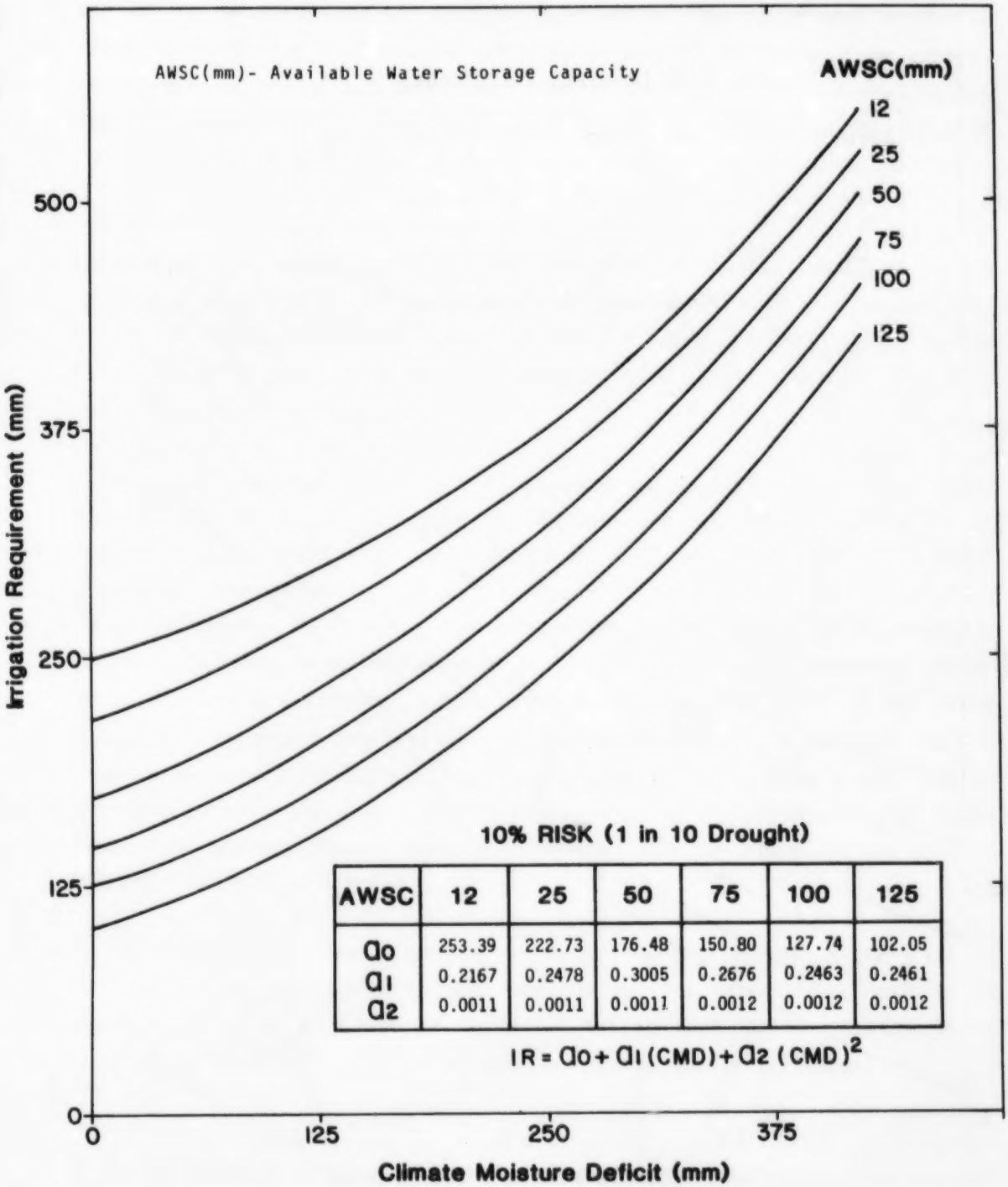
climatological station data for more than 60 locations in Canada (Coligado, Baier, and Sly, 1968). Such techniques cannot be easily applied at all locations of interest, because of the requirement for extensive climatic data and computer analysis.

To overcome these limitations, an empirical calculation method has been proposed, using regression relationships based on the results of the detailed analysis (Sly and Coligado, 1974). The method has been used by Davis (1980) to calculate average seasonal irrigation requirements for 78 British Columbia locations based on the detailed calculations for 15 B.C. locations by Coligado, Baier and Sly (1968). Using the results of the detailed analysis for 15 B.C. locations, relationships of the form:

$$IR = a_0 + a_1 (CMD) + a_2 (CMD)^2 \qquad (3)$$

were determined by curvilinear regression for two risk levels (10% and 50%) and six readily available water storage capacity (SC) values (12, 25, 50, 75, 100 and 125 mm) with CU = 1.0. The values of the coefficients, and the families of curves generated by the regression equations are shown in Figures 2 and 3. Use of this empirical method greatly simplifies the calculation of IR, but it relies on the representativeness of the original locations for which detailed analyses were performed. Analysis of the frequency distributions of seasonal rainfall suggests that this assumption is reasonable. It is assumed in the calculation of IR that the soil is fully recharged with water at the beginning of the growing season, which is reasonable in many locations. However, in a year with a dry spring this assumption would lead to an underestimate of IR. This error could be corrected by choosing a lower value of SC which more closely corresponds to the true soil water storage in that year.

The irrigation requirements calculated at 50% risk level represent the average requirement; the amount calculated would meet or exceed plant demand one year in two. The irrigation requirements calculated at 10% risk level will meet or exceed plant demand in nine out of ten years. The actual amount of water to be applied depends on the efficiency of application. In



10% RISK (1 in 10 Drought)

AWSC	12	25	50	75	100	125
a_0	253.39	222.73	176.48	150.80	127.74	102.05
a_1	0.2167	0.2478	0.3005	0.2676	0.2463	0.2461
a_2	0.0011	0.0011	0.0011	0.0012	0.0012	0.0012

$$IR = a_0 + a_1(CMD) + a_2(CMD)^2$$

Figure 2 IRRIGATION REQUIREMENT VS. CLIMATE MOISTURE DEFICIT AT 10% RISK LEVEL (1 in 10 yr. DROUGHT)

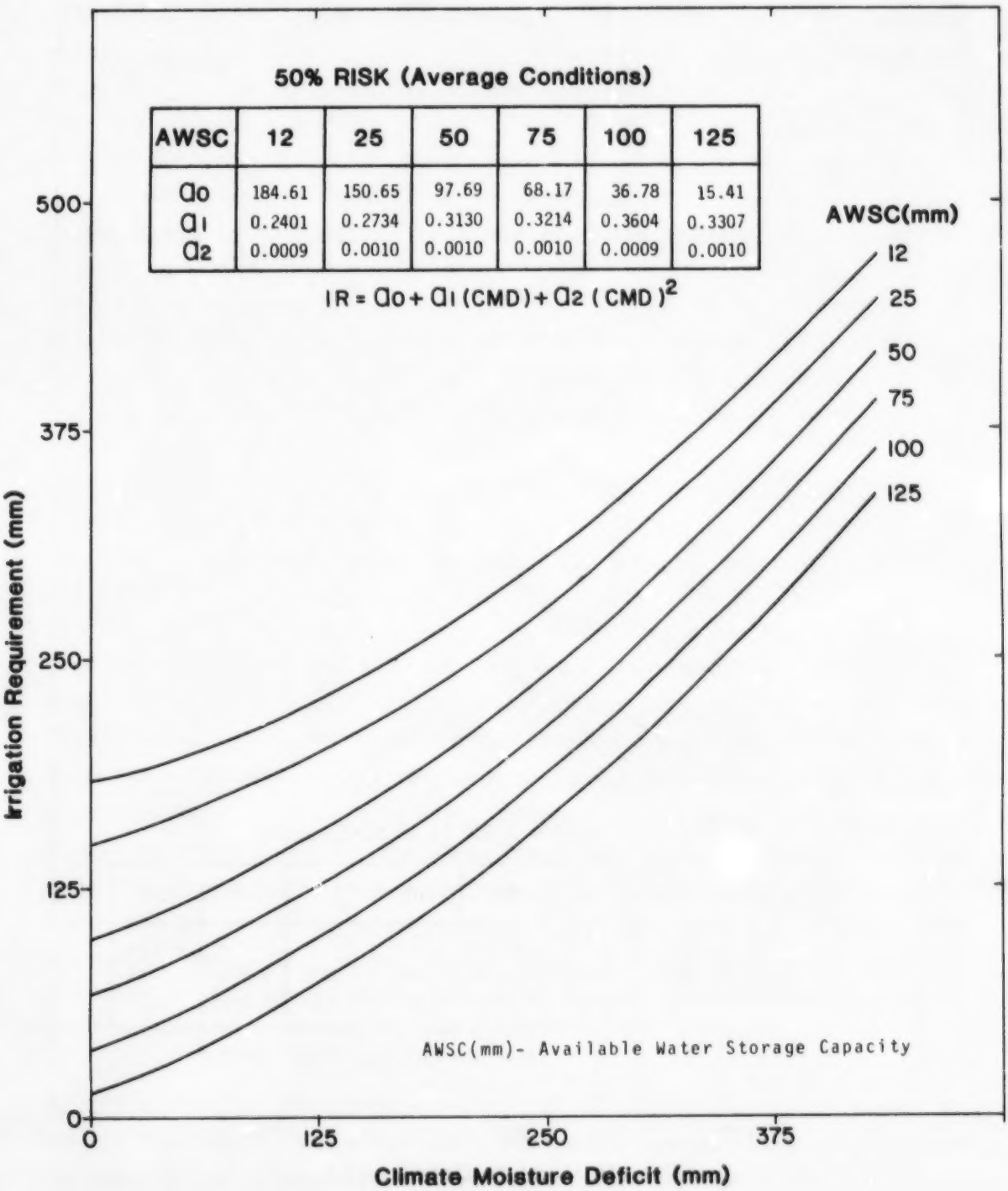


Figure 3 IRRIGATION REQUIREMENT VS. CLIMATE MOISTURE DEFICIT AT 50% RISK LEVEL (AVERAGE CONDITIONS)

the design of an irrigation system, the maximum flow rates must be sufficient to allow for distribution efficiency as well as for extreme events. For details of irrigation design and scheduling, readers are referred to the 1980 Irrigation Design Manual for Farm Systems in B.C. (B.C. Ministry of Agriculture and Food).

Irrigation requirement values can be extracted from Figures 2 and 3, or calculated more accurately using the regression equations. Using an algorithm developed for a programmable Texas Instruments (TI-59) calculator*, values of irrigation requirement for two risk and consumptive use levels (CU), and six values of SC can be generated in a single operation requiring only seasonal P and PE as inputs.

Where a value of irrigation requirement is needed for a site of known CMD and SC, IR can be interpolated between two SC curves. Since the SC intervals are relatively small, linear interpolation is sufficiently accurate. For soils with SC > 125 mm, values of IR must be extrapolated. Figure 4 shows a graph of IR plotted against SC for Duncan, which shows the linearity of the relationship at high values of SC. Each additional increment of readily available storage leads to the same reduction in IR. This suggests that runoff and drainage is virtually constant for SC > 75 mm, and that on average SC is fully utilized only once in the growing season. If SC was utilized for several soil drying cycles, each increment in SC would reduce IR by more than a single increment (and the slope of the line in Figure 4 would be greater).

For soils with low values of SC a considerable amount of rainfall is lost as runoff and drainage, and numerous periods occur which deplete the soil reserve; as a result IR increases faster than SC decreases. As SC approaches zero, all rainfall is lost as runoff, and IR will equal PE.

* Brand names are included for the information of the reader, and are not intended to endorse the product.

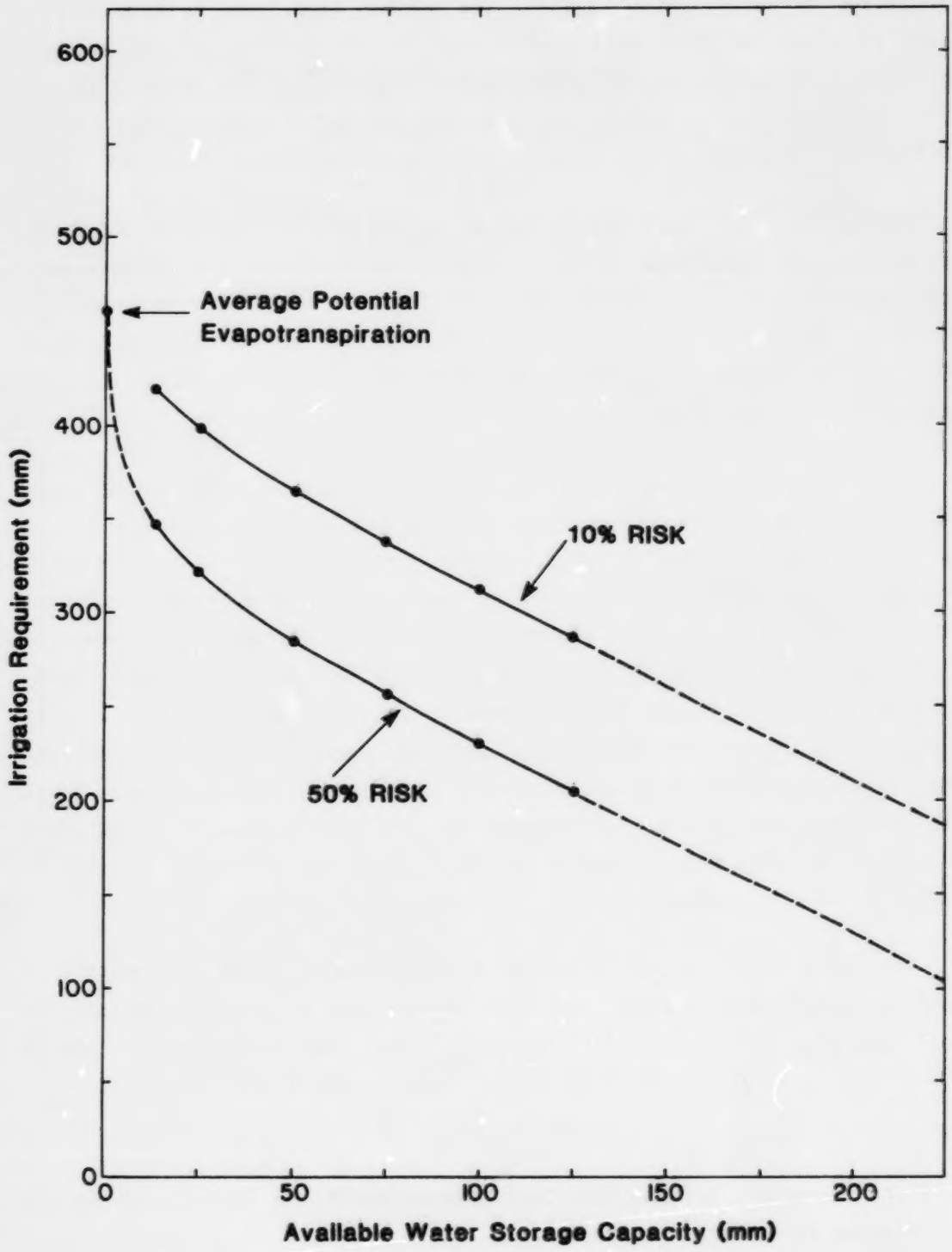


Figure 4 IRRIGATION REQUIREMENT VS. AVAILABLE WATER STORAGE FOR DUNCAN

Extrapolating a value of IR for SC < 12 mm is questionable, since the estimate of IR is sensitive to inaccuracies in SC. Since such coarse soils are generally unsuitable for agricultural use, obtaining an accurate estimate of IR is probably not necessary. In this report the value of IR reported will be the value calculated for SC = 12 mm.

2.4 CLIMATIC MOISTURE INDEX

For agricultural and engineering applications the seasonal irrigation requirement is a useful indicator of water status, but for purposes of soil classification a Climatic Moisture Index (CMI) has been proposed by Sly, (1970). This index indicates the proportion of seasonal water requirements provided by the growing season rainfall. The value of the index approaches 100 in extremely wet locations. It is calculated as follows:

$$CMI = 100\ P\ /\ (P + SC + IR) \qquad (4)$$

In general, CMI is calculated for the period May to September, but sometimes the growing season is considerd to be the period with mean air temperature greater than 5°C. On southeastern Vancouver Island this represents a much longer period (March to November). Since rainfall is high in spring and fall, and plant water demand is relatively low, the value of CMI is considerably higher if the 5°C threshold is used to define the growing season (25 points higher at Saanichton). Sly and Baier (1971) point out that much of the additional rainfall runs off, and suggest that since May to September represents the critical growth period, the index should be calculated for the period May to September. In this report CMI is calculated for the period of May to September.

The calculation of CMI requires an estimate of total seasonal water requirements, (i.e. P + SC + IR). Theoretically, IR is determined as follows:

$$IR = PE - \text{Effective } P - SC \qquad (5)$$

as has been done implicitly in this study. Since Effective P is defined here as (P-Runoff-Drainage)

$$IR = PE - P + Runoff + Drainage - SC \quad (6)$$

Recalling that CMD = PE - P, therefore

$$IR = CMD - SC + Runoff + Drainage \quad (7)$$

In a study by Vold and Marsh (1981) CMI was calculated using an idealized case for IR where runoff was not accounted for, i.e.

$$IR' = CMD - SC \quad (8)$$

Since $IR \geq IR'$ the CMI values determined in their study will be higher (particularly for soils with small AWSC).

The CMI is, as its name implies, an index of the climatic conditions during the growing season. It is therefore useful in comparing climatic regimes, which usually differ only between fairly extensive regions.

For agricultural land capability rating, the contributions of both climatic and soil factors to plant water regime are important. A more useful index might be a Site Moisture Index;

$$SMI = \frac{P + SC}{P + SC + IR} \times 100 \quad (9)$$

which compares the water from rainfall and storage to the total water need. A Site Dryness Index (SDI) can be calculated as the complement of SMI;

$$SDI = \frac{IR}{P + SC + IR} \times 100 = 100\text{-}SMI \quad (10)$$

Table 2 compares the values of the three indices for soils in the Dougan Lake Area.

TABLE 2: MOISTURE INDEX VALUES FOR SOILS OF THE DOUGAN LAKE AREA (P = 160 mm, PE = 360 mm)

Soil	SC	CMI	SMI	SDI
Cowichan	35	37.6	45.9	54.1
Cassidy	9	36.4	38.5	61.5
Chemainus	37	37.9	46.7	53.3
Comiaken	34	37.7	44.8	55.2
Fairbridge	65	39.0	54.9	45.1
Kye	16	36.3	39.9	60.1
Qualicum	8	36.5	38.3	61.7
Shawnigan	18	36.5	40.6	59.4
Salalakim	8	36.5	38.3	61.7

The table shows the sensitivity of SMI in separating sites of differing soil properties. The range of CMI was only 2.7, whereas the range of SMI is 16.6, clearly separating loamy soils with high values of SC from coarser soils which are much drier.

CHAPTER THREE
RESULTS AND DISCUSSION

3.1 VARIATION OF IRRIGATION REQUIREMENT WITH CLIMATE AND SOIL FACTORS

The irrigation requirements calculated for Duncan are shown in Table 3. Similar values generated for a number of other Vancouver Island stations are shown in Appendix B. Several features of the data are noteworthy. The increase of IR from an average year to a one in ten year drought is approximately 75 mm. This represents 21% of IR for SC = 12 mm (a coarse soil), and 40% of IR for SC = 125 mm (loam soil). Since the best soils will generally be the ones to be cultivated and irrigated, the total amount of water required for irrigation in a one in ten-year drought would probably be 30 to 35% higher than for an average year. This increase may be extemely significant in a year when streamflows are already low.

The value of IR calculated for Duncan with SC = 50 mm, and CU = 1.0 is 285 mm under average conditions, which compares well with a value of 240 mm given by Maas (1969) for pasture. However, values given by Maas for Nanaimo and Courtenay for similar conditions (137 mm and 99 mm respectively), differ significantly from those calculated (195 mm and 185 mm, respectively). Since the values used for seasonal precipitation are nearly the same in both cases, the differences are probably due to different PE values used.

If the consumptive use factor of a crop is 0.75 rather than 1.0 a reduction in IR of approximately 90 mm occurs in the pilot area. Since growth generally begins in March for southwestern Vancouver Island, the surface is probably fully covered with vegetation from May until September (CU = 1.0), except in the case of well-spaced row crops. Moisture limitations are seldom severe early in the growing season when CU is less than 1.0.

3.2 CALCULATED IRRIGATION REQUIREMENTS FOR A PILOT AREA

In order to illustrate the use of the method, irrigation requirements for a small pilot area near Cowichan Bay have been calculated and mapped. Figure 5 shows a map of the soils of the pilot area. Irrigation requirements for the soils are shown in Table 4, and maps of IR for 0.5 m and 1.0 m root zone depths with CU = 1.0 are shown in Figures 6 and 7, respectively. Crops with shallower root zones have higher irrigation requirements than deeper rooted crops, since they are not able to withstand short deficit periods. These crops require more intensive water management than can be achieved using seasonal estimates.

The mean values of SC used in calculating IR were obtained from laboratory soil water retention data, or extrapolated from soil physical properties observed in the field. Data for the soils in the pilot area are shown in Appendix A. The pilot area soils range from extremely coarse - textured soils with low values of SC to high-quality agricultural soils such as the Fairbridge loam. Under average conditions (50% risk), for a 0.5 m root zone depth, IR ranges from 185 mm for Fairbridge loam, to 270 mm for Salalakim and Qualicum gravelly sandy loams. For the deeper 1.0 m rootzone, IR is lower, ranging from 30 mm for Fairbridge to 270 mm for Salalakim. IR increases with decreasing risk level, so for 10% risk IR ranges from 265 mm to 340 mm for a 0.5 m root zone depth, and from 205 mm to 335 mm for a 1.0 m root zone.

Appendix B shows values of CMI for some Vancouver Island locations. Values lie between 30 and 45 for the eastern coastal area, reflecting the dry summer conditions. In the pilot area CMI values range only from 36 to 39, reflecting very little of the effects of soil variability on moisture status. Although the index values provide a general indication of the climatic conditions experienced, they do not have sufficient resolution to differentiate agricultural capability at a local scale. The calculation of CMI requires specification of IR, which is considerably more sensitive to soil type, and is therefore a better indicator of water status during the growing season than CMI.

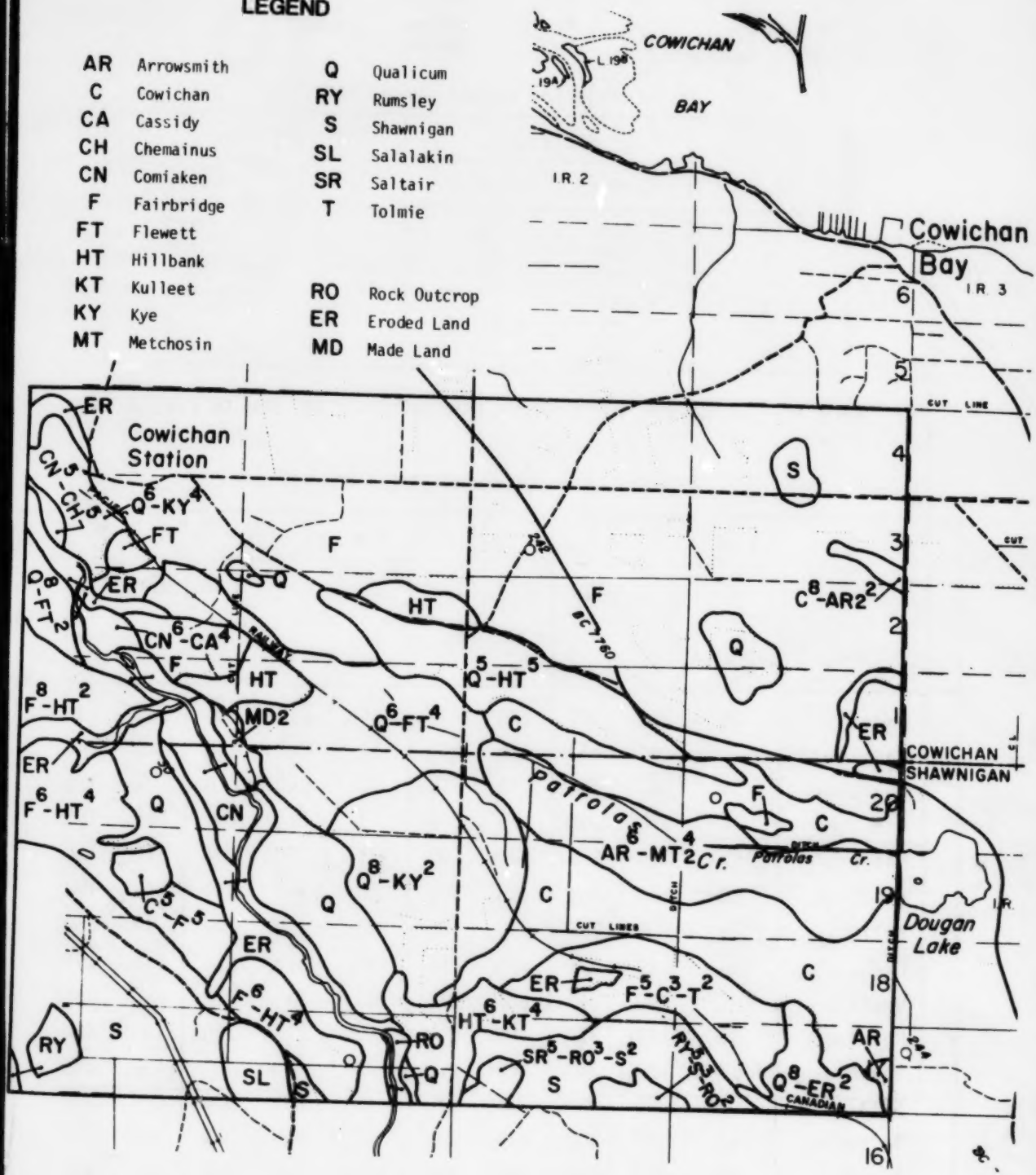


Figure 5 SOILS OF THE DOUGAN LAKE AREA.

TABLE 3: IRRIGATION REQUIREMENTS FOR DUNCAN

PE	460 mm
P	160 mm
CMD	300 mm

Irrigation Requirements (mm)

SC mm	50% Risk		10% Risk	
	CU=0.75	CU=1.0	CU=0.75	CU=1.0
12	265	350	335	420
25	240	325	310	400
50	190	285	270	370
75	165	255	240	340
100	140	230	215	315
125	110	205	190	290

TABLE 4: IRRIGATION REQUIREMENTS FOR SOILS IN THE DOUGAN LAKE AREA

Irrigation Requirement (to nearest 5 mm)

Soil	Risk	10%		50%		Risk	10%		50%	
	CU	0.75	1.0	0.75	1.0	CU	0.75	1.0	0.75	1.0
	SC (mm)					SC (mm)				
Cowichan	35	250	305	175	230	60	215	280	135	190
Cassidy	9*	290	340	225	270	17	280	330	210	260
Chemainus	36	245	300	170	225	60	215	270	135	190
Comiaken	34	250	305	175	230	54	220	280	140	195
Fairbridge	65	205	265	130	185	121	150	205	70	130
Hillbank	52	220	280	145	200	88	185	240	105	160
Kulleet	65	205	265	130	185	90	180	240	100	160
Kye	16	285	335	215	265	57	215	275	135	195
Qualicum	7*	290	340	225	270	32	255	310	180	235
Royston	30	260	310	185	240	60	215	280	135	190
Shawnigan	17	280	330	210	260	33	250	305	180	230
Salalakim	7*	290	340	225	270	15	285	335	220	270
Saltaire	17	280	330	210	260	33	250	305	180	230
Tolmie	52	220	280	145	200	105	165	225	85	145

* For values of SC < 12 mm, IR is calculated for SC = 12 mm

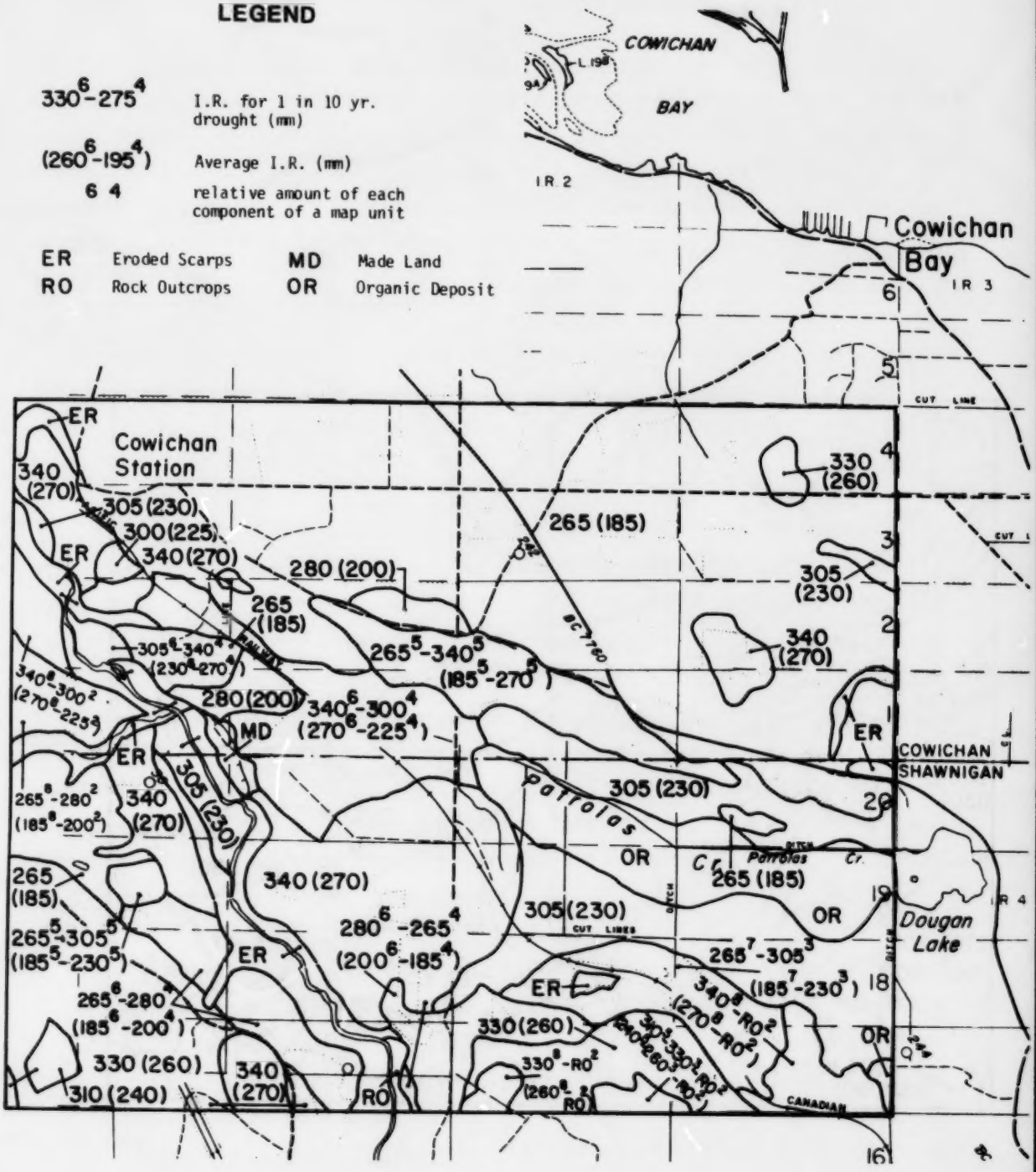


Figure 6 CALCULATED IRRIGATION REQUIREMENT (I.R.) FOR 50 cm ROOT ZONE DEPTH.

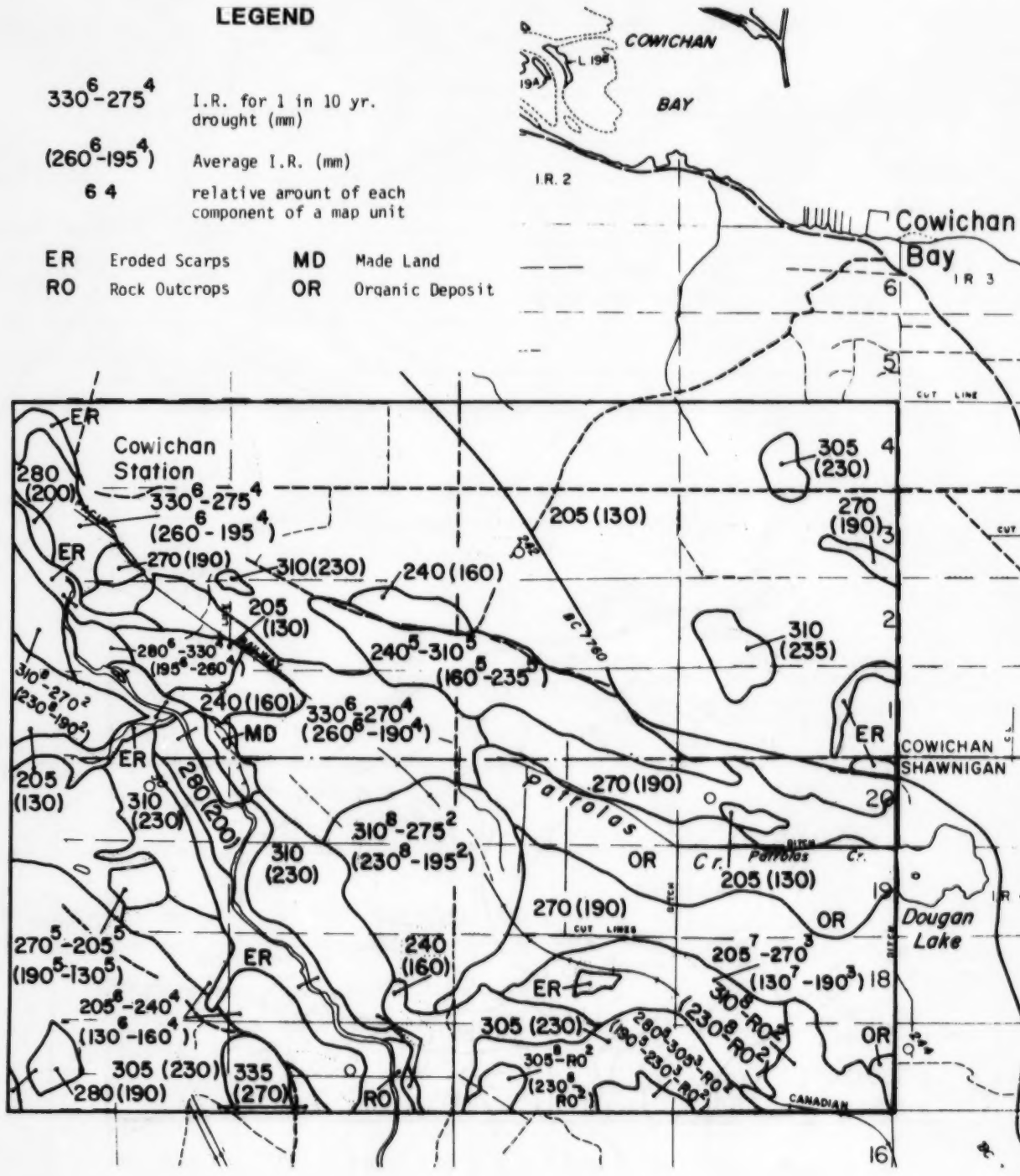


Figure 7 CALCULATED IRRIGATION REQUIREMENT (I.R.) FOR 100 cm ROOT ZONE DEPTH.

3.3 LIMITATIONS AND SOURCES OF ERROR

The calculated values of irrigation requirements are in general agreement with estimates given for the area by experienced agriculturists, but it should be noted that no allowance is made in the calculation for deep drainage or sub-irrigation which may occur. In particular, soils such as the Cowichan, Metchosin, and Arrowsmith soils may receive a substantial portion of their calculated irrigation requirements via sub-irrigation from the local water table.

Because the hydrologic properties of organic soils are significantly different from those of mineral soils, values of IR were not mapped for these soils, although comments made by agriculturists suggest that IR is similar to that for the Cowichan soil.

If values of IR are needed for periods shorter than May to September, a more physically based calculation method should used with daily or weekly data. For some situations a simple budget using P and PE is adequate, but for others it will be necessary to model lateral and vertical flows in the root zone. Such a calculation would provide more accurate estimates of IR than the current method, but it requires considerably more effort and data.

Table 5 summarizes the influence of various soil and climatic factors on the magnitude of the calculated irrigation requirement. There are four main possible sources of error in the current calculations, which are listed below in decreasing order of importance.

1. PE estimation: This may be extremely important in calculating the magnitude of IR, although the relative differences between soils are felt to be realistic. Appendix C contains further discussion of this problem. In the area mapped errors could be from 15 to 70% depending on soil type.
2. Seepage and sub-irrigation: For some soils these processes may significantly reduce IR. At some sites in the Fraser Valley actual IR was only 50% of the value calculated because of the contribution from seepage.

3. If the site of interest differs climatically (in rainfall timing and frequency, etc.) from the regression line calculated for the 15 base stations, values IR may not be estimated accurately. Among the 15 base stations errors of estimation of 10 to 20% were observed, although most stations were estimated to within 10% by regression.
4. SC estimation
   A. Lack of data for some soils
   B. Assumption of full recharge in spring may lead to an underestimate of IR in a dry year.
   C. Actual conditions in a field may differ significantly from the mean value of SC.
5. Calculating 10% risk from 30 year climatic normals is somewhat uncertain, since extreme value predictions are based on few observations. (Average conditions are predicted more accurately than 1 in 10 year floods or droughts).

TABLE 5: INFLUENCE OF CHANGES IN VARIOUS CLIMATE AND SOILS FACTORS ON THE IRRIGATION REQUIREMENT

Change	Factor	Effect on IR
Decrease	CU	Decrease
Decrease	PE	Decrease
Decrease	P	Increase
Decrease	SC	Increase
Decrease	Drainage	Decrease
Decrease	Subirrigation	Increase
Decrease	Seepage	Increase
Decrease	Risk-tolerance	Increase

CHAPTER FOUR
SUMMARY AND RECOMMENDATIONS

Based on water budget calculations for 15 British Columbia locations, a series of curvilinear relationships between irrigation requirement and CMI were developed to describe two levels of consumptive use (CU) and two levels of risk, for six different readily available water storage capacities. The calculation method outlined requires only average values of rainfall and potential evapotranspiration for the May to September period.

An algorithm developed for the programmable TI-59 calculator allows calculation of IR for 24 combinations of risk, CU and SC in a single operation. An interpolation routine developed for the calculator allows the user to generate estimates of IR for four combinations of risk and CU for a specified value of SC. Values of Climatic Moisture Index are also calculated in the algorithm.

Using the interpolation routine, values of IR were calculated and mapped for a small pilot area near Cowichan Bay. These values, when corrected for the effects of sub-irrigation, are felt to be considerably better indicators of growing season water status than CMI.

The recommendations below suggest basic work required to improve the estimates of IR.

1. Field measurements of potential evapotranspiration must be made in order to establish the demand for water.
2. The magnitude of the contribution of water from natural sub-irrigation should be established.
3. Root zone water balance calculations should be performed to determine the irrigation requirements of crops during short periods of critical water shortage, and for periods other than May to September.

Recommendations 1 and 2 require field work to be done during several growing seasons. Recommendation 3 can be addressed using historical climatic data and the soil data used in the current report, but would benefit greatly by information from 1 and 2.

In any attempt to determine the moisture regime of an agricultural area, the following should be considered:

1. The Climatic Moisture Index provides a general indication of the proportion of water required by plants which is provided by growing season precipitation.
2. The Climatic Moisture Deficit provides an estimate of the amount of water required by plants which is not provided by precipitation. CMD does not quantify the actual water requirement because it does not include runoff or the water stored in the root zone.
3. The Irrigation Requirement is a quantitative estimate of the amount of water needed to grow crops without water limitation. It incorporates both climatic and soil characteristics.

In general, the CMI is best used to broadly compare one region to another. The CMD is an estimate of water deficit which requires no soil information. IR is the best estimate of water required for agricultural crops, and is the most useful parameter for evaluating water status at a local scale.

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APPENDIX A
SOIL KEY AND AWSC DATA

The soil key is subject to revision as the Vancouver Island survey progresses. The key was prepared by the Terrestrial Studies Branch.

The AWSC data are based on laboratory determinations of water retention characteristics (1/3 - 15 bar tensions). In some cases values were extrapolated from field data, based on relationships developed between texture, bulk density and AWSC.

SOIL KEY

Symbol	Name	Most* Common Texture	Most Common Drainage	Most** Common Soil	Description
FINE MARINE SOILS					
C	Cowichan	sic-cl / sic	poor	HU.LG	Found in wet depressional areas. Includes Includes minor areas of O.HG.
F	Fairbridge	sil,sil / sicl	imperfect	GLE.DYB	A major soil in the Duncan area. Inclusions of O.SB (old cultivate fields).
HT	Hillbank	l,sil,fsl	mod. well	O.DYB (E.DYB)	Better drained portion of Fairbridge soil.
GRAVELLY FINE TEXTURED MARINE OVER MARINE/TILL					
KT	Kulleet	gl,gsil,gcl,gsicl / gsl,gsl,gs	imperfect	GL.DYB	Level areas.
COARSE TEXTURED MARINE/FLUVIAL UNDERLAIN BY FINE MARINE					
T	Tolmie	scl-l / sicl	poor	O.HG	Level to depressional areas.
COARSE TEXTURED MARINE/FLUVIOGLACIAL, FLUVIAL					
Q	Qualicum	vgs,vgls,vgsl	rapid to well	O.DYB	Beach deposits, fluvio-glacial and glacial and fluvial deposits. Minor inclusions of O.SB (i.e. old cultivated fields).
KY	Kye	ls,sl	rapid	O.DYB (E.DYB) (O.HFP)	Sandy aeolian, marine beach on fluvial deposits. Minor inclusions of O.SB (cultivated fields).
MEDIUM TEXTURED FLUVIOGLACIAL, FLUVIAL					
FT	Flewett	l,fsl	well	O.DYB (O.HFP)	Level terraces not affected by groundwater. Upward fining trend in profile.

SOIL KEY (CONTINUED)

Symbol	Name	Most* Common Texture	Most Common Drainage	Most** Common Soil	Description
FLOODPLAIN AND LOWER LEVEL TERRACES					
CA	Cassidy (complex)	vgls,vgsl	rapid to mod.well	CU.R	Generally occurs near present rivers and creeks. Includes CU.HR, O.R, O.HR.
CN	Comiaken (complex)	ls,sl	rapid to well	CU.R O.SB	Sandy fluvial deposits. Includes O.SB (old cultivated fields). Includes CU.HR, O.R., O.HR.
Ch	Chemainus (complex)	fsl,l,sil	mod. well	O.DYB (CU.R)	Fine textured fluvial deposits. Includes O.SB (some cultivated fields). Includes minor areas of O.R, O.HR.
MORAINAL SOILS					
S	Shawnigan	vgsl	mod. well, (imperfect)	DU.DYB	Major till soil.
R	Royston	gl,gcl	imperfect	GL.DYB	Weak to no cementation in this soil.
SHALLOW TO BEDROCK SOILS					
SL	Salalakim	vgls	rapid	O.DYB	Conglomerate bedrock.
RY	Rumsley	vgls	well	O.DYB	Volcanic bedrock.
SR	Saltair	vgls	well	O.DYB	Intrusive bedrock.
ORGANIC SOILS					
MT	Metchosin	humic	poor, very poor	TY.H	Common soil.
AR	Arrowsmith	mesic	very poor	TY.M	Less common found.

SOIL KEY (CONTINUED)

Symbol	Name	Most* Common Texture	Most Common Drainage	Most** Common Soil	Description
MISCELLANEOUS LAND TYPES					
MD	Made Land				Man made lands.
RO	Rock Outcrop				
ER	Eroded Scarps				

* Texture Class + Soil Type

s	sand
si	silt
c	clay
l	loam
g	gravelly (20 - 50% gravels)
vg	very gravelly (50 - 90% gravels)

** Refer to: The Canadian System of Soil Classification 1978. Can. Dep. Agric. Pub. 1646. Supply and Services Canada, Ottawa, Ont. 164 pp.

TABLE A.1: AVAILABLE WATER STORAGE CAPACITY DATA FOR SOILS IN THE DOUGAN LAKE AREA (0.5 m ROOT ZONE DEPTH)

Series	n*	Mean AWSC (mm)	Range	Mean AWSC (mm) (corrected for coarse fragments)	Range
Brigantine	1	40	-	40	-
Bellhouse	1	100	-	75	-
Cowichan	1	70	-	70	-
Cassidy	1	35	-	18	-
Crofton	2	93	85-100	93	85-100
Chemainus	3	73	45-100	73	45-100
Comiaken	2	68	60- 75	68	60- 75
Dashwood	3	42	35- 50	27	20- 30
Fairbridge	6	130	80-175	130	80-175
Hillbank	1	105	-	105	-
Kye	3	33	15- 60	32	15- 55
Mill Bay	1	70		70	-
Metchosin	1	85	-	85	-
Qualicum	1	20	-	15	-
Rumsley	2	100	90-110	60	45- 75
Shawnigan	5	65	50- 75	35	25- 40
Shawnigan	1	60	-	30	-
Salalakim	1	35	-	15	-
Saltair	1	70	-	35	-
Saturna	2	50	40- 60	28	20- 35
Tolmie	1	105(est.)	-	105(est.)	-

n* number of AWSC determinations used in calculating mean.
(est.) For some soils, AWSC data is incomplete and extrapolation was used to calculate the water retained in the 0-100 or 0-50 cm depth.

TABLE A.2: AVAILABLE WATER STORAGE CAPACITY DATA FOR SOILS IN THE DOUGAN LAKE AREA (1.0 m ROOT ZONE DEPTH)

Series	n*	Mean AWSC (mm)	Range	Mean AWSC (mm) (corrected for coarse fragments)	Range
Brigantine	2	110	-	110	-
Bellhouse		(not applicable - always a shallow soil over rock)			
Cowichan	3	120	115-125	120	-
Cassidy	1	70(est.)	-	35(est.)	-
Crofton	3	218	210-225	218	210-225
Chemainus	7	123	55-195	121	55-195
Comiaken	4	108	90-125	108	90-125
Dashwood	4	52	45- 60	32	25- 35
Fairbridge	10	241	135-355	241	135-355
Hillbank	2	175	-	175	-
Kye	4	118	100-145	117	100-140
Mill Bay	2	110	-	90	-
Metchosin	2	100	-	100	-
Qualicum	2	70	-	65	-
Rumsley	2	200(est.)	180-220	120(est.)	90-150
Shawnigan	8	122	95-155	67	50- 85
Shawnigan	2	85	-	40	-
Salalakim	1	70(est.)	-	30(est.)	-
Saltair	1	140(est.)	-	70(est.)	-
Saturna	2	100(est.)		56(est.)	(usually 100 cm of soil over bedrock)
Tolmie	1	210(est.)	-	210(est.)	-

n* Number of AWSC determinations used in calculating mean.
(est.) For some soils, AWSC data is incomplete and extratopation was used to calculate the water retained in the 0-100 or 0-50 cm depth.

APPENDIX B

IRRIGATION REQUIREMENTS FOR SOME VANCOUVER ISLAND LOCATIONS*

Station Name	P	PE	CMD	CMI	SC (mm) 12	25	50	75	100	125	SC (mm) 12	25	50	75	100	125
					50% Risk						10% Risk					
Victoria (Gonzales)	110	320	210	30	280	250	205	180	155	130	345	325	290	260	235	205
Saanichton	140	340	200	36	270	245	200	175	145	120	340	315	280	250	225	200
Cowichan Bay	160	350	190	40	265	240	195	165	140	115	335	310	275	245	220	195
Duncan	160	460	300	32	345	325	285	255	230	205	420	400	370	340	315	290
Cowichan Lk.	255	415	160	54	245	215	170	145	115	90	315	290	250	220	195	170
Nanaimo	190	385	195	44	270	240	195	170	140	115	335	315	275	245	220	195
Port Alberni	250	440	190	50	265	240	195	165	140	115	335	310	275	245	220	195
Comox	190	365	175	45	255	230	185	155	130	105	325	300	265	235	210	185

* All values are rounded to the nearest 5 mm.

The stations above represent much of the agricultural area of Vancouver Island. The similarity of CMD values, with the exception of Duncan, is striking, suggesting that the calculated values of IR for the pilot area should be useful for much of the eastern coastal area.

APPENDIX C
CALCULATION OF POTENTIAL EVAPOTRANSPIRATION

M.C. Coligado and C.H. Wallis

C.1 COMPARISON OF CALCULATION METHODS

Potential evapotranspiration is the most important climatic parameter in determining plant demand for water, but no satisfactory routine measurement technique exists. Evaporation pans and other measuring devices are susceptible to errors due to advection. Theoretical equations for PE exist (Monteith, 1965) but measurement of the parameters in the equation is not practical.

Empirical formulae have been developed to describe PE in terms of routinely available parameters. Baier and Robertson (1965) developed a series of regression equations to calculate PE using different climatic parameters, based on climatic data from across Canada. Their equation 3, PE(BR3), requires maximum temperature (MAX), temperature range (ΔT), incoming solar radiation at the top of the atmosphere (Q_o), and vapour pressure deficit (vpd), and is of the following form:

$$PE(BR3) = a + b(MAX) + c(\Delta T) + d(Q_o) + e(vpd) \qquad (C.1)$$

where a, b, c, d, and e are regression coefficients. The equation is well-suited to network climatic data and has been adjusted to B.C. coastal conditions using Baier and Robertson's equation 8 for stations where sunshine and wind data are available as follows:

$$PE(ASB) = 0.66\ PE(BR3) - 88.4\ mm \qquad (C.2)$$

This adjustment is required since equation (C.1) weights temperature range (ΔT) heavily in the estimation of PE, and locations subject to a strong maritime influence have narrow temperature ranges. PE estimates made for

made for coastal locations using equation C.1 are therefore considerably lower than those made using methods which rely more on radiation data, such as that developed by Priestley and Taylor (1972); as follows:

$$PE(PT) = \alpha \left(\frac{s}{s+\gamma}\right) (Q^* - Q_G)/L \qquad (C.3)$$

where s, γ and L are the slope of the saturation vapour pressure curve, the psychrometric constant, and the latent heat of vapourization, respectively, determined at ambient air temperature. Q^* is the net radiation flux density, Q_G is the soil heat flux density, and α is an experimentally determined coefficient. In many studies the value of α has been found to be 1.25 ± 0.05 for actively transpiring crops (Priestley and Taylor, 1972; Davis, 1978; Wallis, 1981). Equation C.3 can be used when Q^* can be measured or modelled (from solar radiation and air temperature) and when the value of α is known, since Q_G is often calculated as a fraction of Q^*.

Table C.1 compares estimates of PE made using equations C.2, and C.3. Values of Q^* for equation C.3 were obtained using a regression of Q^* versus hours of bright sunshine (Linacre, 1968) using an albedo of 0.25. It has been assumed that $Q_G = 0$ on a seasonal basis (Davis, 1978).

PE estimates using Priestley and Taylor (PE (PT)) and using Baier and Robertson equation 3 adjusted to coastal conditions (PE (ASB)) for selected major sites on Vancouver Island were compared. Figure C.1 shows the very wide scatter of the points along the line with a slope of 1 and an intercept of 0.0. It appears that these estimates share little or no correlation. However, when the percent differences between the two estimates,

$$\% \text{ Difference} = \frac{PE\ (PT) - PE\ (ASB)}{PE\ (PT)} \times 100 \qquad (C.4)$$

TABLE C.1: SEASONAL ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION USING TWO DIFFERENT EQUATIONS (rounded to the nearest 5 mm)

Station Name	PE(PT)	PE(ASB)
Agassiz CDA	400	395
Alberni (Lupsi Cupsi)	435	420
Campbell River	435	380
Cowichan Bay	445	345
Cowichan Lake (For.)	390	415
Nanaimo	445	385
Saanichton CDA	460	340
Victoria (Gonzales)	480	320

are plotted against the distances of the sites from the nearest ocean, Figure C2 reveals the influence of the ocean on PE (ASB). The land-ocean interface is classically a cause of distinct meso-meteorological phenomena such as sea-breeze and land-breeze associated with contrasting surface temperatures. It is also conceivable that during warm, sunny summer days, moisture is being advected to this interface, which could change the atmospheric moisture profile. This could change the evapotranspiration that would otherwise be determined by the energy available. (On homogenous, flat, extensive areas with adequate fetch to prevent the advection of energy and moisture, evapotranspiration is primarily determined by the energy available.)

Baier and Robertson, in establishing their empirical formulae, did not have enough samples to show, test or explain Figure C2. However, if in fact, the zone of the land-ocean interface is affected by moisture advection from the ocean, then the PE values from the Baier and Robertson formula may not be underestimations of PE in the area. On the other hand , if PE in this zone is determined as theorized by Priestley and Taylor (with $\alpha = 1.25$) then the PE estimates used in this paper should be adjusted. There are no evapotranspiration data available for the agricultural areas of Vancouver Island, but the experience of agriculturists suggests that the temperature-based Baier and Robertson estimates are too low.

In the calculation of CMD(PE-P), any uncertainty in PE becomes a larger proportion of the final value and of the calculated irrigation requirements. Table C.2 shows the estimates of IR calculated using the Priestley and Taylor and adjusted Baier and Robertson values of PE, and the ratio, for several stations on Vancouver Island. The estimates of IR differ considerably for large values of SC implying that estimates of IR for agricultural soils are sensitive to uncertainties in PE and CMD. The values for Saanichton show that an uncertainty of 22% in PE leads to an uncertainty of as much as 80% in IR for average conditions. Estimates of water deficit for coastal areas can probably be intercompared with reasonable confidence, even though their absolute magnitude may be questionable. A project proposed for the 1981 and 1982 growing seasons should help to refine the estimates given in this paper.

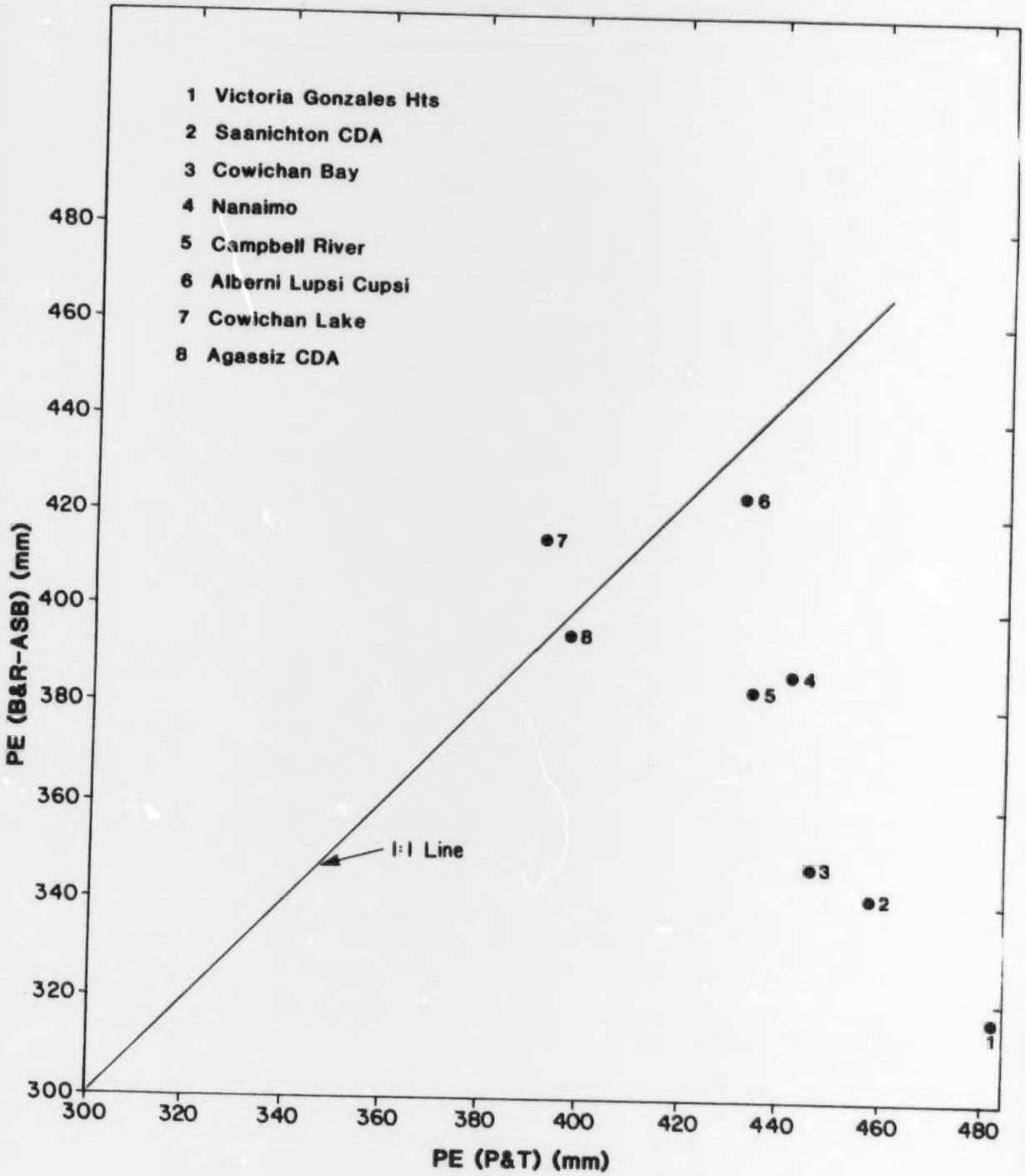

Figure C1 COMPARISON OF PE ESTIMATES FOR STATIONS WITH MARITIME INFLUENCE

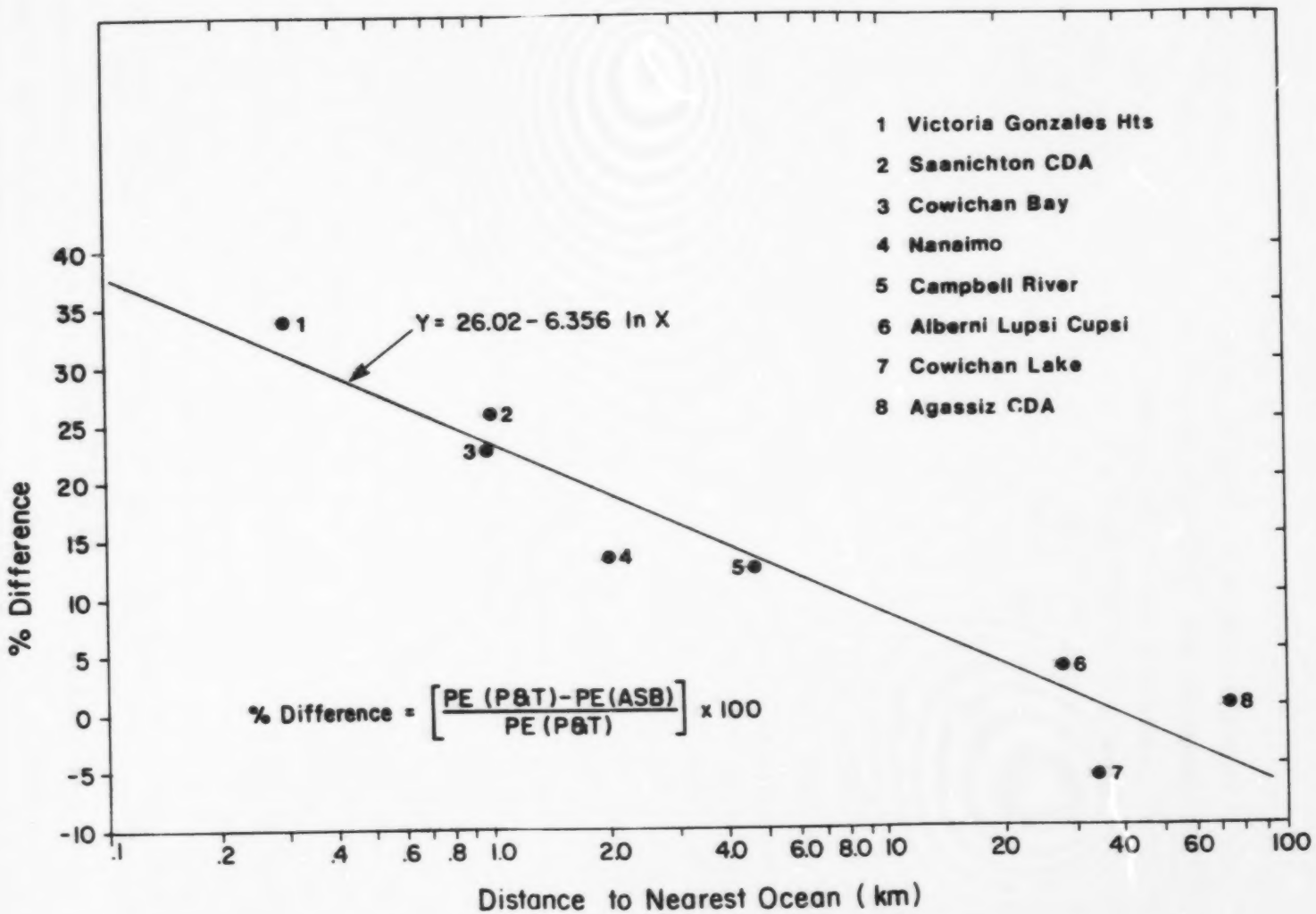

Figure C2 THE EFFECTS OF DISTANCE TO THE NEAREST OCEAN ON PE(ASB) ESTIMATES

TABLE C.2: ESTIMATES OF IRRIGATION REQUIREMENT USING TWO DIFFERENT VALUES OF POTENTIAL EVAPOTRANSPIRATION

50% Risk													
Station	SC (mm)	12		25		50		75		100		125	
	CU	.75	1.0	.75	1.0	.75	1.0	.75	1.0	.75	1.0	.75	1.0
Cowichan Bay	B.R.	220	266	189	238	141	193	112	165	84	139	60	114
	P.T.	258	336	230	312	185	271	157	245	130	220	105	194
	Ratio	117	126	122	131	131	140	140	148	155	158	175	170
Nanaimo	B.R.	217	268	187	241	138	196	109	168	81	142	57	117
	P.T.	238	307	209	282	162	240	134	213	106	187	82	162
	Ratio	110	115	112	117	117	122	123	127	131	132	144	138
Saanichton	B.R.	226	273	196	246	148	202	119	174	92	148	67	123
	P.T.	275	361	248	338	203	299	176	272	150	248	124	221
	Ratio	2	132	127	137	137	148	148	156	163	168	185	180
Victoria Gonzales	B.R.	233	278	203	252	156	207	127	180	100	154	75	128
	P.T.	308	412	283	391	241	354	214	328	189	303	163	277
	Ratio	132	148	139	155	154	171	169	182	189	197	217	216
10% Risk													
Station	SC (mm)	12		25		50		75		100		125	
	CU	.75	1.0	.75	1.0	.75	1.0	.75	1.0	.75	1.0	.75	1.0
Cowichan Bay	B.R.	287	334	260	310	219	273	191	244	166	218	140	193
	P.T.	326	408	302	388	265	355	235	326	210	300	184	274
	Ratio	114	122	116	125	121	130	123	134	127	138	131	142
Nanaimo	B.R.	285	337	258	313	216	276	188	247	163	221	138	195
	P.T.	306	378	280	356	241	322	212	292	187	267	161	241
	Ratio	107	112	109	114	112	117	113	118	115	121	117	124
Saanichton	B.R.	294	342	267	319	226	282	198	253	173	227	147	201
	P.T.	343	434	320	416	284	385	254	355	228	329	203	304
	Ratio	117	127	120	130	126	137	128	140	132	145	38	151
Victoria Gonzales	B.R.	300	347	274	324	234	288	206	259	180	233	155	207
	P.T.	379	488	358	472	324	443	294	414	268	389	242	364
	Ratio	126	141	131	146	138	154	143	160	149	167	156	176

B.R.: IR' calculated using PE(ASB)
P.T.: IR calculated using PE(PT)
Ratio = $\frac{\text{P.T.}}{\text{B.R.}} \times 100$

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